

Broadband Acoustic Clutter

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LONG TERM GOALS

The long term goal is to improve performance of low-mid frequency active sonar systems against clutter.

OBJECTIVES

The objectives are to identify/understand the mechanisms that lead to clutter and develop models that predict the temporal/spatial/frequency dependence of the observed clutter and background diffuse reverberation.

APPROACH

The experimental approach is based upon exploiting both long-range observations of clutter and short-range, or direct-path observations (seabed scattering and reflection) of the features that give rise to the clutter. Direct path observations offer two significant advantages: a) the uncertainties associated with propagation (through a generally sparsely sampled ocean) are minimized, and b) the measurement geometries are favorable to producing data from which hypotheses about the scattering mechanisms can be directly tested. The theoretical approach for diffuse reverberation and clutter is based in part on energy flux methods.

WORK COMPLETED

A short summary of FY10 efforts include:

- 1) Developed method for estimation of sediment sound speed variability from seabed bi-static scattering measurements
- 2) Developed simple, intuitive theory for propagation in a waveguide with range-dependent seabed properties
- 3) Developed high-fidelity clutter and target echo model that is computationally very efficient

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RESULTS

The FY10 work included analysis of seabed scattering data from the Clutter09 experiment as summarized below. The analysis extracted seabed sound speed spatial variability down to a lateral resolution of roughly 50m. The results provide a first look at geoacoustic variability around a seabed feature (mud volcano cluster) known to cause sonar clutter (see Refs [1-2]). While the mechanism that gives rise to the clutter is understood (meter-scale carbonate chimneys on the flanks of the mud volcanoes), it is of importance to understand the propagation to and from these features.

The majority of the FY10 effort was focused on theoretical and model development. Since, discrete clutter features generally exist in a range-dependent seabed environment, it was of substantial interest to further our understanding of the effects of that range-dependence on clutter. As a first step, the effects of seabed range-dependence on propagation was studied in detail through development of a simple intuitive theory. The theory provides important insights into the effects of seabed variability and uncertainty on propagation. Finally, a model was developed to improve the fidelity of clutter and target echo response while still retaining computational efficiency.

Seabed sound speed spatial variability from AUV scattering data

Seabed scattering data were collected during the Clutter09 experiment using a towed source and receive array behind an AUV (see track line in Fig 1a). Figure 1b shows the measured data from a single ping scaled by two-way spreading where the polar coordinate system is centered on the middle of the receive array (mra) and the AUV direction is approximately west-southwest. The source and mra are separated by ~27m, the AUV height above the seabed is ~18m. One interesting (and exploitable) feature of the scattering data is the behavior at specular, i.e., where the incident and scattered vertical angles are identical (with varying azimuth angle). The specular returns are characterized by high intensity returns that are approximately perpendicular to the AUV direction (see Fig 1b).

Scattering theory indicates that at the seabed critical angle, specular scattering will exhibit a peak and then rapidly decrease (dropping off as the 4th power of the sine of the grazing angle at low angles). This peak can be seen in Fig 1b and also on the broadside beam time series of Fig 2a (seen as two hyperbolae just before the white dotted lines). The range-dependent seabed sound speed, c_{sed} , can be estimated from the arrival time, t , of the specular peak and knowledge of the AUV height, h , and sound speed, c_{wat} , (constant between the source, bottom and receiver) $c_{sed} = c_{wat} / \sqrt{1 - (2h/ct)^2}$. The resulting sound speed estimates are shown in Fig 2b, where the underlying spatial resolution of the data is about 50 m. Note the low sediment sound speeds toward the southwest of the bathymetric features. Those features are mud volcanoes and are formed by the expulsion of fluidized mud, which has sound speeds at (or sometimes below) the sound speed of the water column, here 1512 m/s. Interestingly, there is a sound speed minimum on the southwest flank of the mud volcano, suggestive that the most recent ebullition events occurred at or near that location. Lateral sound speed gradients are highest near the peaks of the mud volcanoes (rather than the sound speed minimum) with a maximum value of ~0.2 m/s/m. Future plans are to use the full bi-static scattering data to estimate scattering parameters (e.g., roughness) as well as geoacoustic properties from these data.

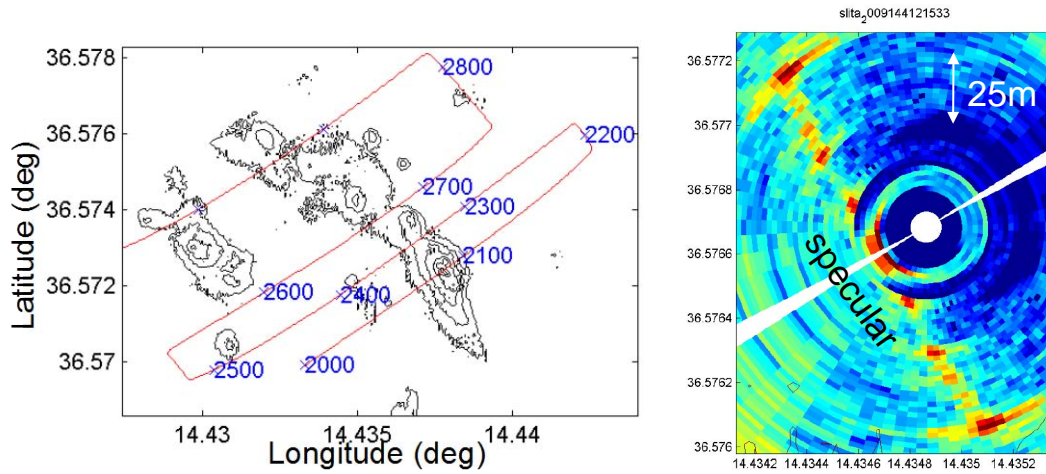


Figure 1. The map shows the AUV track (red line) overlaid on multibeam bathymetry. Mean water depth is about 165m, depth contours are in 1m increments. The ping numbers are in blue. At right is 1600-3500 Hz seabed scattering data at ~ping 2450; data are plotted in dB with a varying gain of 15 log(range) and a color dynamic range of 60 dB. The specular return is apparent as high amplitude returns (in red) perpendicular to the AUV direction.

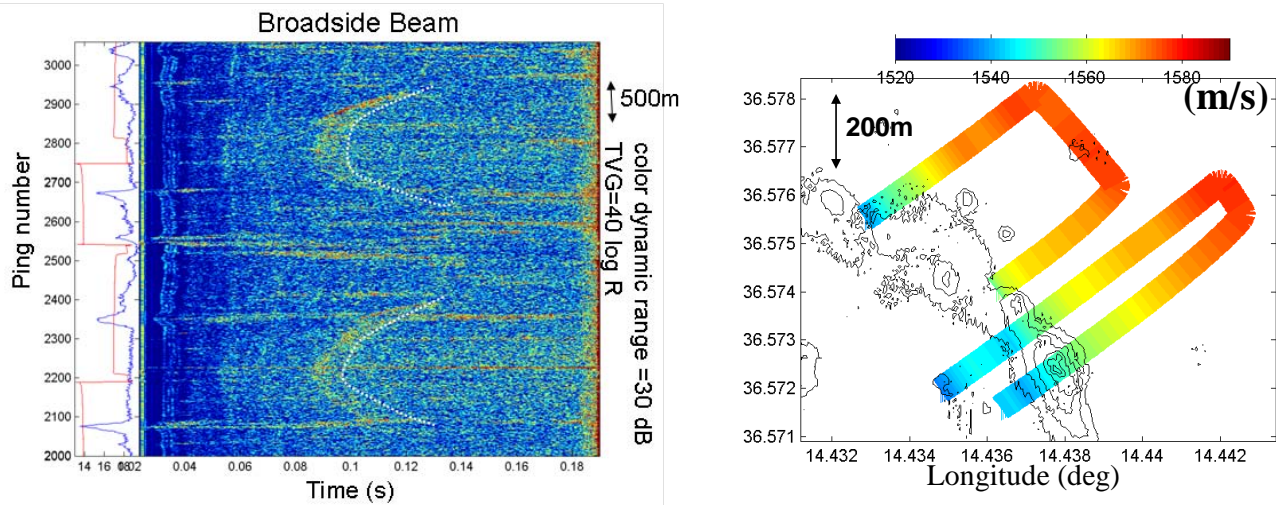


Figure 2. a) broadband scattered intensity on the broadside beam along the track shown in Fig 1a. The peak of the specular are seen as two hyperbolae (white dotted lines have been offset from the peaks as a visual clue). Other strong returns associated with strong discrete seabed scatterers (e.g., carbonate chimneys, see Ref [2]) are also seen. b) sediment sound speed estimated from the peak of the specular returns. Note the low sound speeds associated with the southwestern flanks of the mud volcano.

Intuitive theory for effects of range-dependent seabed properties on waveguide propagation

In order to understand reverberation and clutter in a complex, range-dependent environment, it was important first to develop an understanding of the effects of range-dependence upon propagation. To this end a simple and intuitive theory for propagation in a waveguide with range-dependent boundary conditions was developed (see Ref [3]) based on energy flux principles. It turns out that the propagation can be understood simply in terms of the geometric mean of the range-variable plane-wave reflection coefficient and the arithmetic mean of the cycle distance. This simplicity allows significant insight into the relationship between the geoacoustic variability (and/or uncertainty) and the propagation variability (and/or uncertainty). Ten principles were derived from the theory and it was shown that many complex environments can be understood from a few of those principles (for more details see Ref [3]). Two examples of the accuracy of the theory are shown in Fig 3, where the theory compares favorably with the parabolic equation model, RAM.

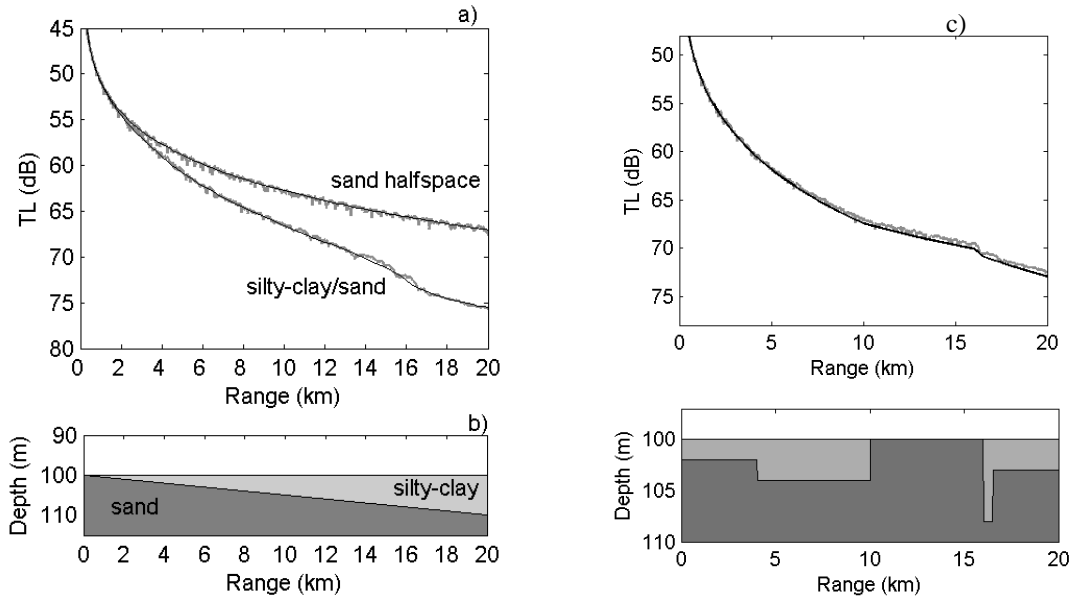


Figure 3. comparison of new theory (black) with RAM (gray) at 500 Hz for a) slow sediment wedge and c) a highly faulted environment with vertical discontinuities at the basement (sand).

High-fidelity clutter and target echo calculations using an energy flux approach

Previous energy flux approaches, e.g., [4] yield smooth estimates of the temporal decay of a clutter or target echo, which may be sufficient in some applications. However, some applications, e.g., interpretation of measured clutter, or sonar simulations of clutter and target echo, require high fidelity estimates of the clutter time series response. Work is underway to extend fast calculations using energy flux ideas with pseudo modes to provide estimates of clutter and target time series response. Using the normal mode calculations as a benchmark (see Figure 4), note that the energy flux with pseudo modes (EFpm) result has the correct general temporal structure, but is substantially

computationally faster. The calculations using pseudo modes are only slightly slower than the ‘smooth’ energy flux (EF) calculation.

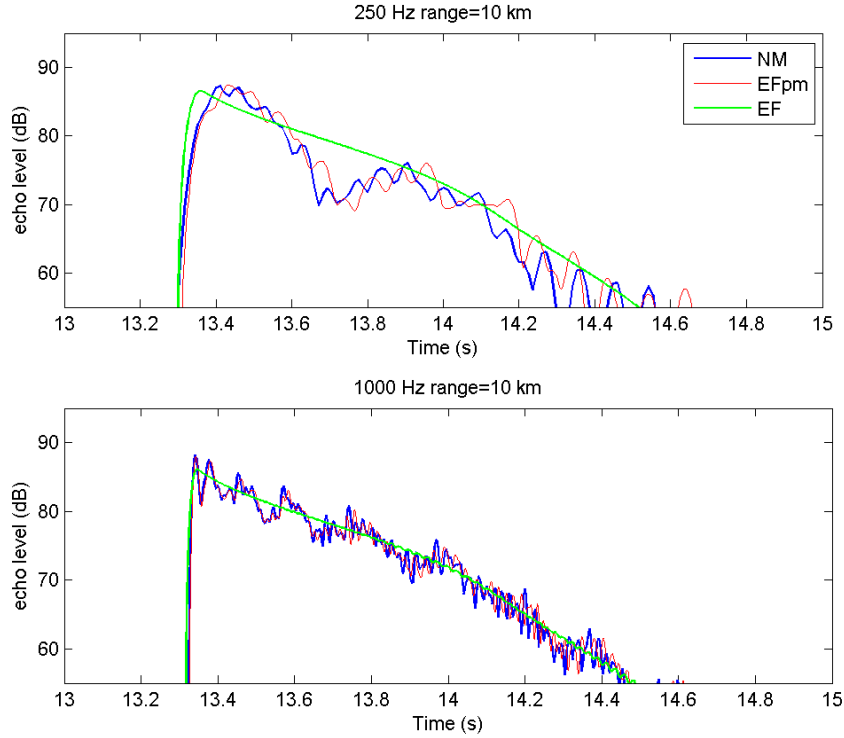


Figure 4. *echo from a target sphere at 10m depth from a normal mode model (in blue, courtesy of Dale Ellis), energy flux model (green) and energy flux using pseudo modes and Lloyd mirror model (red). The target sphere is at 10 km range and the calculations were performed at 250 Hz and 1000 Hz.*

IMPACT/APPLICATIONS

The modeling approaches are useful for transition to the HiFAST/SAST programs inasmuch as they are extremely computationally efficient. One specific example would be the clutter or target echo structure calculations (as shown in Fig 4) in which realistic fluctuations in the echo structure could be very useful for simulation and training with little computational overhead. Another example is the new theory for propagation in a waveguide with range-dependent boundaries [3], which has potential to speed up point-to-point calculations by replacing a range-dependent marching solution with a range-independent solution using the geometric mean of the reflection coefficient and the arithmetic mean of the cycle distance. For incoherent models (e.g., ASPM) this could further enhance speed of computation, without loss of accuracy.

The sediment lateral sound speed variability analysis is useful as a first step towards estimation of small-scale geoacoustic variability including roughness and potentially volume heterogeneity. This is an important step towards development of a new tool for measurement of seabed scattering on scales that are crucial for understanding and predicting sonar clutter.

TRANSITIONS

The seabed scattering data from this program have been transitioned to the PMW-120 Ocean Bottom Characterization Initiative (OBCI, Marcus Speckhahn, program manager) for development of a seabed scattering database for the Naval Oceanographic Office. The scattering data have already been key to the determination of which modeling approach to use for database construction.

RELATED PROJECTS

This project is part of the Broadband Clutter Initiative Joint Research Project (JRP) including ARL-PSU (USA), DRDC-A (CAN), the NATO Undersea Research Centre (Italy) and NRL-DC (USA).

PMW-120 OBCI Program: Measurement results and techniques developed in this program are being transitioned to the survey community and also to the design of the first generation Naval Oceanographic Office bottom scattering database.

ONR Applied Reverberation and Modeling Board: that board seeks to enhance transitions of basic research in reverberation modeling to the applied community.

ONR Quantifying Predicting and Exploiting (QPE) Uncertainty: data/methods for quantifying geoacoustic variability and uncertainty developed in this project are being leveraged to QPE.

REFERENCES

- [1] Holland C.W., T. Weber, and G. Etiope, Acoustic Scattering from Mud Volcanoes and Carbonate Mounds, *J. Acoust. Soc. Am.*, 120, 3553-3565, 2006.
- [2] Holland C.W., J.R. Preston, and D.A. Abraham, Long-range acoustic scattering from a shallow-water mud volcano cluster *J. Acoust. Soc. Am.*, 122, 1946-1958, 2007.
- [3] Holland, C.W., Incoherent acoustic propagation over a range-dependent seabed, *J. Acoust. Soc. Am.*, in press.
- [4] Harrison C.H. and P. L. Nielsen, Multipath pulse shapes in shallow water: Theory and simulation *J. Acoust. Soc. Am.*, 121, 1362-1373, 2007.

PUBLICATIONS

Holland, C.W., Incoherent acoustic propagation over a range-dependent seabed, *J. Acoust. Soc. Am.*, [in press, refereed].

Holland C.W. and Ellis, D.D., Shallow water reverberation from a sub-bottom interface: a comparison of modeling approaches, *J. Comp. Acoust.*, 17, 29-43, 2009. [published, refereed]

Dettmer J., S.E. Dosso, and C.W. Holland, Model selection and Bayesian inference for high resolution seabed reflection inversion, *J. Acoust. Soc. Am.*, 125, 706-716, 2009. [published, refereed]

Holland C.W., Fitting data, but poor predictions: Reverberation prediction uncertainty when seabed parameters are derived from reverberation measurements, *J. Acoust. Soc. Am.*, 2553–2562, 123, 2008. [published, refereed]

Holland C.W., Reverberation and clutter from sub-bottom mechanisms, in International Symposium on Underwater Reverberation and Clutter, edited by P.L. Nielsen, C.H. Harrison, and J-C LeGac, Lerici, Italy, 113-122, Sept. 2008. [published]

Abraham D.A. and C.W. Holland, Spatially Compact Clutter, in International Symposium on Underwater Reverberation and Clutter, edited by P.L. Nielsen, C.H. Harrison, and J-C LeGac, Lerici, Italy, 199-208, Sept. 2008. [published]

Nielsen P.L., Harrison C.H., and C.W. Holland, Local bottom characterization using an Autonomous Underwater Vehicle (AUV), in International Symposium on Underwater Reverberation and Clutter, edited by P.L. Nielsen, C.H. Harrison, and J-C LeGac, Lerici, Italy, 345-352, Sept. 2008. [published]

Dettmer J., S.E. Dosso , and Holland C.W., Joint time/frequency-domain inversion of reflection data for seabed geoaoustic profiles, *J. Acoust. Soc. Am.*, 123, 1306-1317, 2008. [published, refereed]

Guillon L. and C.W. Holland, Coherence of signals reflected by the seafloor: numerical modeling vs. experimental data, *Traitement du Signal (French)*, 25, 131-138, 2008. [published, refereed]

Gerig A., and Holland C.W., Near-specular acoustic scattering from a buried mud volcano, *J. Acoust. Soc. Am.*, 122, 3280-3285, 2007. [published, refereed].

Dettmer J., Dosso S.E. and Holland C.W., Full-wavefield reflection coefficient inversion, *J. Acoust. Soc. Am.*, 122, 3327-3337, 2007. [published, refereed]

Holland C.W., Preston J.R., and D.A. Abraham, Long-range acoustic scattering from a shallow-water mud volcano cluster *J. Acoust. Soc. Am.*, 122, 1946-1958, 2007. [published, refereed]